# New Low Thermal Conductivity Particleboard from Durian Peel Fiber and Durian Peel Powder-based Adhesives

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***Abstract***

The main goal of this research was to produce and evaluate the new low thermal conductivity particleboard from durian peel fiber and durian peel powder-based adhesives. Chemical composition of durian peel fiber and powder were undertaken to evaluate the performance of produced particleboards. Physical Properties (Moisture Content, Thickness Swelling and Water Absorption), Mechanical Properties (Internal bond, Modulus of Rupture and Modulus of Elasticity) and Thermal Properties (Thermal Conductivity) were determined. These durian peel powder-based adhesive particleboards were counterbalanced by the advantages of being formaldehyde-free which makes them a suitable alternative for indoor applications.

***Keywords**:* Durian Peel, Particleboards, Chemical composition, Thermal conductivity

## 1. Introduction

Particleboard is a wood-based composite consisting of varying shapes and sizes of particles of lignocellulosic material bonded together with an adhesive and consolidated under heat and pressure. Ther worldwide demand of particleboard has been growing. From the viewpoint of waste-to-building material, durian peel has been the most attractive available agricultural residues as [1] it has the lowest thermal conductivity of 0.0921 W/m.K and bulk density of 472 $kg/m^3$. Using them to manufacture a particleboard [2] to reduce heat transfer into space in order to decrease the energy consumption of building facilities is a beneficial form of sustainable development. However, [2-3] produced durian peel particleboard using synthetic binder; Urea-Formaldehyde (UF), Phenol-Formaldehyde (PF) and Isocyanate. The adhesive used to bond the particle come from synthetic adhesives. Nowadays, most of the commercial produced particleboard is bonded with formaldehyde-base adhesive. The global trend indicated that the marketplace is moving towards using particleboards with reduced or no formaldehyde. Formaldehye-based adhesives such as UF and PF resins dominate the current wood adhesive market. Despite the notorious of such resins, formaldehyde emissions and their non-renewable nature have become matter of increasing concern. Therefore, environmentally friendly adhesives from renewable resources and free from formaldehyde are nowadays developed to replace the UF and PF binders.

Bonding is an important aspect of binderless boards. Self-bonding can be achieved by chemical activation reaction and physical consolidation of particles under applied heat and pressure [4-5]. Degradation of hemicelluloses and partial degradation of cellulose to produce simple sugars has been reported to contribute to bonding [4]. Bonding can also be caused by cross-linking carbohydrate polymers and lignin. Binderless boards have been developed from sugar-containing lignocellulosic material such as sorghum. Free sugars, carbohydrates or saccharides in lignocellulose plants served as bonding and bulking agents.

At the present time, due to simultaneous awareness increase on environment and energy, increase attention should be paid to natural fibers and binder with a view to conserving energy and protecting the environment. Production of particleboard with low thermal conductivity for building using natural fiber as durian peel fiber and natural binder as durian peel powder is an interesting alternative which would solve environment and energy concern.

The objective of this study was to examine the chemical composition of durian peel, durian peel fiber and durian peel powder and to produce and evaluate the new low thermal conductivity particleboard from durian peel fiber and durian peel powder-based adhesives.

## 2. Material and Methods

### 2.1Determination of the chemical Composition of durian peel, durian peel fiber and durian peel powder

It is necessary to know the basic and chemical properties of raw materials. The results of durian peel, durian peel fiber and durian peel powder chemical analysis performed following TAPPI standards are shown in Table 1.

Table 1 Chemical composition of durian peel, durian peel fiber and durian peel powder

| Chemical Composition | Durian Peel (%) | Durian Peel Fiber (%) | Durian Peel Powder (%) |
|---|---|---|---|
| Ash content | 4.26 | 3.87 | 4.20 |
| Alcohol-benzene solubility | 20.7 | 22.0 | 18.9 |
| Hot-water solubility | 33.3 | 38.2 | 37.6 |
| 1% NaOH solubility | 54.7 | 56.0 | 56.7 |
| Lignin (ash corrected) | 15.5 | 10.1 | 9.89 |
| Holocellulose | 48.5 | 48.6 | 47.2 |
| Pentosan | 12.3 | 12.4 | 14.9 |

**• Alpha-, beta- and gamma-cellulose in pulp (TAPPI T 203 om-93)**

Alpha-cellulose is the pulp fraction resistance to 17.5% and 9.45% sodium hydroxide solution under condition under conditions of the test. It indicates undegraded, higher-molecular-weight cellulose content in pulp. Beta-cellulose is the soluble fraction that is reprecipitated on acidification of the solutions. It indicated that of degraded cellulose. Gamma-cellulose is that fraction remaining in the solution. It consists mainly of hemi-cellulose.

**•Solvent extractives of wood and pulp (TAPPI T 204 om-88)**

Soluble material or extractives in wood consist of those components that are soluble in neutral organic solvents.The dichloromethane-extractable content of wood is measure of such substance as waxes, fats, resins, photo sterols and nonvolatile hydrocarbons. The amount is markedly influenced by seasoning or drying of the wood. The ethanol-benzene and ethanol-toluene extractable content of wood consists of certain other dichloromethane-insoluble components, such as low-molecular-weight carbohydrates, salts and other water-soluble substances. Since the pulping process usually removes most water-soluble and volatile compounds that are also soluble in organic solvents, the solvent extractable materials in pulp may be considered to consist primarily of resin and fatty acids and their esters, waxes and unsaponifiable substances. No single organic solvent is capable of removing all these substances and different solvents remove different combinations. The mixture, ethanol-benzene appears to provide the most complete removal of residual solvent-extractable substance in pulp.

**• Water Solubility of wood and pulp (TAPPI T 207 om-93)**

The cold-water procedure removes a part of extraneous components such as inorganic compounds, tanning, gums, sugars and colourings matter present in wood and pulp. The hot-water procedure removes in addition starches.

**• Ash in pulp (TAPPI T 211 om-93)**

The ash content of the sample may consist of (a) various residues from chemicals used in its manufacture, and (b) metallic matter from piping and machinery. The amount and composition of the ash is a function of the presence or absence of any of these material or others singly or in combination. No specific qualitative meaning is attached to the term “ash” as used in this test method. Where a further qualitative examination of the ash is desired, this method may be used in combination with TAPPI T 421 “Qualitative (Including Optical Microscopic). Ash, the material remaining is calculated on the basis of the dry weight of the original sample, after the sample is ignited at a specified temperature. Ash at 535 °C means the ash content of the sample when the ignition temperature is 525 °C.

**• One percent sodium hydroxide solubility of wood and pulp (TAPPI T 212 om-93)**

Hot alkali solution extracts low-molecular-weight carbohydrates consisting mainly of hemicellulose and degraded cellulose in wood and pulp. The solubility of pulp could indicated the degree of a fungus decay or of degradation by heat, light, oxidation, etc. As the wood decays or degrades, the percentage of the alkali-soluble material increases. The solubility of pulp indicates an extent of cellulose degradation during pulping and bleaching processes and has been related to strength and other properties of pulp.

- **Acid-insoluble lignin in wood and pulp (TAPPI T 222 om-88)**

Lignin represents what is called the "incrusting material" forming a part of the cell wall and middle lamella in wood. It is an aromatic, amorphous substance containing phenolic methoxyl, hydroxyl and other constituent groups; its chemical structure has not been fully elucidated.

It can be seen that the chemical composition of durian peel, durian peel fibres and durian peel powder is similar as shown in Table 1. They all contain lignin and hemicellulose. As a result, durian peel fiber and durian peel powder have high 1%NaOH solubility which hot alkali solution extracts low-molecular-weight carbohydrates consisting mainly of hemicellulose and degraded cellulose in wood and pulp.Lignin represents what is called the "incrusting material" forming a part of the cell wall and middle lamella in wood. It is an aromatic, amorphous substance containing phenolic methoxyl, hydroxyl and other constituent groups.

**2.2 Durian peel powder and Durian peel fiber Preparation**

Durian peel powder was made as follows; the first step was to reduce the fresh durian peel to approximately chip size. The chip size pieces were oven-dried at 80 ºC for 8 h. Dried durian peel chips were hammermilled. Durian peel powder for being natural adhesives were screened by sieved over 80-100 mesh screen. Then, fibers were screen to remove excess fines by sieve machine over a 60 mesh screen. Durian fruit, fresh durian peel, dried durian peel and dried durian fibres are shown in Figure 1.

Fig. 1 Durian fruit (Top-Left), fresh durian peel (Top-Right), dried durian peel (Bottom-Left) and dried durian fibre (Bottom-Right)

**2.3 Boards Preparation and Testing**

The procedure for preparing specimens was done as follows; weighing durian peel powder and fiber sample according to the desired ratio as shown in Table 3. Add exact volume of water and mix well. The blended particles were felted by hand into the final mat with a forming box (250 mm x 250 mm). The formed particlemat were pressed at a platen temperature of 150 ºC. A pressure of 1000 and 1500 Psi was applied for the boards. After the hot pressing, the boards were drying at temperature of 80, 90 and 100 °C in order to be completely cured for 24 h and the trimmed and cut into various test specimens. Afterwards, testing specimens were carried out for physical and thermal properties. Testing specimens were carried out according to JIS A 5908-2003 (Japanese Standard Associating, 2003) for physical properties; density, moisture content, thickness swelling. The Thermal conductivity of the particleboards was measured by using a thermal conductivity analyzer NETZSCH Model HFM 436 Lamda according to ASTM C 518 (American Society for testing and Materials).

Table 2 Mixing Ratio (Fiber: Powder: Water) and Drying temperature

| Board | Mixing Ratio (Fiber:Powder:Water) and Drying Temperature | |
|---|---|---|
| 1 | 1:1:1 | (80 ºC) |
| 2 | 1:1:1.5 | (80 ºC) |
| 3 | 2:1:1.5 | (80 ºC) |
| 4 | 2:1:2 | (80 ºC) |
| 5 | 1:1:1 | (90 ºC) |
| 6 | 1:1:1.5 | (90 ºC) |
| 7 | 2:1:1.5 | (90 ºC) |
| 8 | 2:1:2 | (90 ºC) |
| 9 | 1:1:1 | (100 ºC) |
| 10 | 1:1:1.5 | (100 ºC) |
| 11 | 2:1:1.5 | (100 ºC) |
| 12 | 2:1:2 | (100 ºC) |

Fig. 2 New low thermal conductivity particleboard from durian peel fiber and durian peel powder-based adhesives

## 3. Result and Discussion

### 3.1 The Physical and Thermal Properties

The Physical and thermal properties is shown in Table 3. Table 4 presents the mechanical properties. It was found that the optimum mixing ratio (durian fiber: durian powder: water) was 2:1:1.5 drying at 100 ºC that the particleboard have the best physical properties, mechanical properties and the lowest thermal conductivity.

Table 3 Physical and Thermal Properties of Particleboards

| Board | Density ($g/cm^3$) | Moisture Content (%) | Thickness Swelling (%) | Thermal Conductivity (W/m.K) |
|---|---|---|---|---|
| 1 | 0.76 | 19.96 | 70 | 0.110 |
| 2 | 0.80 | 19.68 | 60 | 0.137 |
| 3 | 0.80 | 14.88 | 60 | 0.141 |
| 4 | 0.87 | 18.87 | 50 | 0.137 |
| 5 | 0.77 | 12.5 | 60 | 0.101 |
| 6 | 0.80 | 17.81 | 50 | 0.117 |
| 7 | 0.80 | 10.03 | 50 | 0.119 |
| 8 | 0.75 | 13.36 | 50 | 0.088 |
| 9 | 0.80 | 8.39 | 40 | 0.084 |
| 10 | 0.82 | 10.75 | 30 | 0.100 |
| 11 | 0.82 | 8.809 | 30 | 0.109 |
| 12 | 0.80 | 10.34 | 30 | 0.081 |

It was found that dried durian peel could be used to replace formaldehyde-based resin for particleboard manufacture. The properties of durian peel powder-based adhesive board were with in the range of synthetic-based adhesive (UF, PF and IC). The optimum mixing ratio (durian fiber: durian powder: water) was 2:1:1.5 drying at 100 ºC that the particleboard have the best physical properties and the lowest thermal conductivity.

Table 4 Mechanical Properties of Particleboards

| Board | Density ($g/cm^3$) | Internal Bond (MPa) | Modulus of Rupture (MPa) | Modulus of Elasticity (MPa) |
|---|---|---|---|---|
| 1 | 0.76 | 0.06531 | 1.283 | 127.204 |
| 2 | 0.80 | 0.08626 | 0.825 | 82.544 |
| 3 | 0.80 | 0.06104 | 1.138 | 102.866 |
| 4 | 0.87 | 0.01330 | 0.593 | 46.022 |
| 5 | 0.77 | 0.01347 | 0.969 | 91.716 |
| 6 | 0.80 | 0.02160 | 0.888 | 73.995 |
| 7 | 0.80 | 0.02765 | 0.773 | 71.758 |
| 8 | 0.75 | 0.01980 | 0.766 | 77.711 |
| 9 | 0.80 | 0.06080 | 0.906 | 90.420 |
| 10 | 0.82 | 0.03128 | 0.665 | 55.756 |
| 11 | 0.82 | 0.04739 | 1.648 | 132.790 |
| 12 | 0.80 | 0.02877 | 0.481 | 43.360 |

For mechanical properties, it was found that The optimum mixing ratio (durian fiber: durian powder: water) was 2:1:1.5 drying at 100 ºC that the particleboard have the best mechanical properties. As a result, this mixing ratio gave the highest durian fiber content. In addition, the temperature of drying is 100 °C providing continually contribute bonding. Bonding is an important aspect of binderless boards. Selfing bonding can be achieved by chemical activation and reaction and physical consolidation of particles under applied heat and pressure [4]. Degradation of hemicellulose and partial degradation of cellulose in durian peel fiber and durian peel powder to produce simple sugar has been reported to contribute to bonding. In addition, durian peel fiber and durian peel powder have lignin amounts ranging from 9-11%. Lignin has been reported to play an important role in self-boning boards [6]. However, the overall average Internal bond, Modulus of Rupture and Modulus of Elasticity value are lower than the minimum require these value as state by Japanese Standards. It is well know that the mechanical properties is adversely influence by the absence of any adhesive in this technology [7]. Besides, a previous binderless particleboard from oil palm trunk study carried out by Hashim et al. The mechanical properties of binderless particleboard from oil palm trunk did not meet the standard values, as well. They has also resulted in reduced the mechanical properties values of binderless panels manufactured from oil palm trunk.

### 3.2 Comparison between UF, PF and IC-based particleboard and new low thermal conductivity particleboard from durian peel fiber and durian peel powder-based adhesives

A comparison of density and thermal conductivity of UF, PF and IC-based adhesives particleboards and binderless particleboard is shown in Table 5. This reveals that the densities of synthetic based adhesive- particleboards are not different from binderless particleboards. However, the thermal conductivity of binderless particleboard is less than synthetic-based adhesive particleboard because binderless particleboard has hydrogen bonding while synthetic-based adhesive particleboards have strong covalent bonding and so they have high mechanical properties and thermal conductivity.

Table 5 Comparison between Durian peel particleboard using synthetic adhesives and durian peel powder-based adhesive
(5.1 Density and Thermal Conductivity)

| Types of Adhesives | Density ($g/cm^3$) | Thermal Conductivity (W/m.K) |
|---|---|---|
| Urea Formaldyhyde (UF) | 0.907 | 0.1513 |
| Phenol Formaldyhyde (PF) | 0.822 | 0.1854 |
| Isocyanate (IC) | 0.881 | 0.1854 |
| Durian Peel Powder-based adhesive (2:1:1.5 drying temp at 100 ºC) | 0.809 | 0.1090 |

Table 5 Comparison between Durian peel particleboard using synthetic adhesives and durian peel powder-based adhesive
(5.2 Internal Bond, Modulus of Rupture and Modulus of Elasticity)

| Types of Adhesives | Internal Bond (MPa) | Modulus of Rupture (MPa) | Modulus of Elasticity (MPa) |
|---|---|---|---|
| Urea Formaldyhyde (UF) | 1.8936 | 25.177 | 3776.10 |
| Phenol Formaldyhyde (PF) | 1.8373 | 24.70 | 3346.78 |
| Isocyanate (IC) | 1.7560 | 12.26 | 7474.63 |
| Durian Peel Powder-based adhesive (2:1:1.5 drying temp at 100 ºC) | 0.04739 | 1.648 | 132.790 |

## 4. Conclusion

The experimental investigation indicated that the use of durain peel powder to be as natural adhesive to produce particleboard with low thermal conductivity is feasible. The manufactured binderless boards could be used as component of construction panel for energy conservation in building. It was found that dried durian peel could be used to replace formaldehyde-based resin for particleboard manufacture. The properties of durian peel powder-based adhesive board were with in the range of synthetic-based adhesive (UF, PF and IC). The optimum mixing ratio (durian fiber: durian powder: water) was 2:1:1.5 drying at 100 ºC that the particleboard have the best physical properties and the lowest thermal conductivity. That is an important feature to promote the use of this particleboard to be as a component of construction panels for energy conservation of buildings.

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